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For: METHOD FOR FILTERING SEISMIC DATA, PARTICULARLY BY KRIGING

DECLARATION

I, Andrew Scott Marland, of 35, avenue Chevreul, 92270 BOIS COLOMBES, France, declare that I am well acquainted with the English and French languages and that the attached translation of the French language PCT international application, Serial No. **PCT/FR03/00099** is a true and faithful translation of that document as filed.

All statements made herein are to my own knowledge true, and all statements made on information and belief are believed to be true; and further, these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any document or any registration resulting therefrom.

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METHOD FOR FILTERING SEISMIC DATA, PARTICULARLY BY KRIGING

GENERAL TECHNICAL FIELD - BACKGROUND ON KRIGING ANALYSIS

The present invention relates to filtering seismic data, in particular by kriging analysis.

Kriging analysis enables a random function to be resolved from its covariance function.

In particular, it is conventionally used in geostatistics for filtering seismic data, particularly but in non-limiting manner, for characterizing reservoirs.

Kriging analysis relies in particular on the assumption that a phenomenon measured locally by means of optionally-regular sampling can be analyzed as a linear sum of a plurality of independent phenomena, the variogram of the overall phenomenon corresponding to the linear sum of the variograms of each of the independent phenomena making it up.

Conventionally, the variogram corresponding to the measured experimental data is resolved as sum of modeled variograms, and from the experimental data and the models selected for the individual variograms used to resolve the data, there are deduced the individual functions that make up the random function corresponding to the overall phenomenon.

It is thus possible to extract from a seismic data map of the type shown in Figure 1 (e.g. raw experimental data) firstly the white noise that is present in the data (Figure 2a), secondly noise corresponding to linear lines (Figure 2b), and finally filtered data cleared of both of these kinds of noise (Figure 2c).

The kriging calculations for determining the values of the individual functions into which an overall random function is resolved are themselves conventionally known to the person skilled in the art.

In this respect, reference can be made, for example, to articles and publications mentioned in the bibliography given at the end of the present description.

Very generally, the value of an individual function involved in making up the overall random function is determined as being a linear combination of experimental values for points in an immediate neighborhood of the point under consideration, these experimental values being given weighting coefficients.

In other words, if it is considered that a function Z(x) is made up as the sum of individual functions $Y^u(x)$, this can be written:

$$Z(x) = \sum_{u=1}^{U} Y^u(x)$$

and the component $Y^u(x)$ is estimated by:

$$Y^{u*}(x) = \sum_{\alpha=1}^{N} \lambda_u^\alpha Z_\alpha$$

where α is a dummy index designating the points under consideration around the point $\underline{x}$ for which it is desired to determine the estimated value $Y^{u*}(x)$, Z_x being the value at the point $\underline{x}$, N being the number of such points.

It can be shown that the weighting coefficients $\lambda\alpha$ satisfy the equation:

$$\begin{pmatrix} C_{11} \ldots C_{1N} \\ \vdots \quad\quad \vdots \\ C_{N1} \ldots C_{NN} \end{pmatrix} \begin{pmatrix} \lambda_u^1 \\ \vdots \\ \lambda_u^N \end{pmatrix} = \begin{pmatrix} C_{01}^u \\ \vdots \\ C_{0N}^u \end{pmatrix}$$

where the index 0 designates the point for which an estimate is to be determined, the values C_{01}^u to C_{0N}^u being the covariance values calculated from the model $\underline{u}$ corresponding to the component Y^u (values of the covariance function for the distances between each data point and the point to be estimated), the values C_{ij} being covariance values calculated as a function of the selected model for the variogram of the function to be estimated (values of the covariance function for the distances between the data points).

These weighting coefficients λ_u^x are thus determined merely by inverting the covariance matrices.

PROBLEMS POSED BY THE STATE OF THE ART - SUMMARY OF THE INVENTION

One of the difficulties of presently-known kriging analysis techniques is that they require the use of models of the covariance functions.

The advantage of using such models is that they make it possible to have matrices which are defined, positive, and invertible.

Nevertheless, it will be understood that although such filtering techniques give good results, they are strongly dependent on the individual expertise of the person selecting the models for the various variograms.

That can be a source of error, and prevents those techniques being used by people who are not specialists.

Furthermore, selecting models also leads to significant losses of time in production.

An object of the invention is to mitigate that drawback and to propose a filtering technique using kriging analysis that can be implemented in automatic or almost automatic manner.

The invention provides a method of filtering at least two series of seismic data representative of the same zone, by determining (e.g. by determining the cross variogram of the data series and solving the co-kriging equation) an estimate of the component that is common to the data series, and deducing a resolution of these data series is deduced from the estimate.

The invention also provides a method of processing seismic data in which a filter method of the above-specified type is implemented in order to compare two series of seismic data corresponding, for the same zone, to grids of at least one common attribute obtained for two distinct values of at least one given parameter.

The invention also provides a method of filtering at least one series of data representative of the values of at least one physical parameter over at least one zone, characterized by identifying a model of a component of three-dimensional variability of its variogram, substracting said model from the experimental variogram, and solving the kriging equation corresponding to the different variograms in order to deduce an estimate of the corresponding variability component on the data series.

BRIEF DESCRIPTION OF THE FIGURES

Other characteristics and advantages of the invention appear further from the following description which is purely illustrative and non-limiting and should be read with reference to the accompanying drawings, in which:

· Figures 1 and 2a, 2b, and 2c, described above, illustrate an example of seismic data mapping and of the corresponding resolution by kriging analysis;

· Figures 3a and 3b show two maps of the same zone, obtained from acquisitions undertaken at two different times;

· Figure 4 is a map of the component that is common to the maps of Figures 3a and 3b;

· Figures 5a and 5b and Figures 6a and 6b are maps of components other than the component that is common to the maps of Figures 3a and 3b; and

· Figures 7a to 7c are graphs showing the distribution of errors respectively when using standard filtering, filtering by conventional factorial kriging, and filtering as proposed by the invention (factorial co-kriging).

DESCRIPTION OF ONE OR MORE IMPLEMENTATIONS OF THE INVENTION

Automatic filtering

It is assumed that two maps are available that have been obtained for the zone with seismic data acquired, for example, at different instants or for seismic attributes that are different.

By way of example, these two maps are of the type shown in Figures 3a and 3b.

The two functions corresponding to these two data series are written Z1 and Z2 below.

It is proposed to resolve each of these two functions into the sum of their common component plus orthogonal residues.

For this purpose, there is determined, from two data series for which a cross variogram is available having the following values:

$$\gamma_{12}(h)=\frac{1}{N}\sum(Z1(x)-Z1(x+h))(Z2(x)-Z2(x+h))$$

where $\underline{x}$ and x+h designate the pairs of points taken into consideration in the direction and for the distance $\underline{h}$ for which the value of the variogram is determined, and where N is the number of pairs of points for said direction and said distance.

Knowing this cross variogram, an estimate is then determined of the function corresponding thereto, which satisfies:

$$Z^*_{12}(x)=\sum_{\alpha=1}^{N}\lambda^1_\alpha Z^1_\alpha+\sum_{\beta=1}^{N}\lambda^2_\beta Z^2_\beta$$

where α and β are two dummy indices designating the points taken into consideration around the point $\underline{x}$ for which it is desired to determine an estimate of said function, Z^1_α and Z^2_β being the value at said point $\underline{x}$, N being the number of said points, and where λ^1_α and λ^2_β are weighting coefficients.

These weighting coefficients λ^1_α and λ^2_β are determined by inverting the co-kriging equation:

$$\begin{bmatrix} C_{11}11 & \dots & C_{11}N1 & C_{11}11 & \dots & C_{11}11 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ C_{11}1N & \dots & C_{11}NN & C_{12}11 & \dots & C_{12}NN \\ C_{21}11 & \dots & C_{21}N1 & C_{22}11 & \dots & C_{22}N1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ C_{21}1N & \dots & C_{21}NN & C_{22}11 & \dots & C_{22}NN \end{bmatrix} \begin{bmatrix} \lambda_{11} \\ \dots \\ \lambda_{1N} \\ \lambda_{21} \\ \dots \\ \lambda_{2N} \end{bmatrix} = \begin{bmatrix} C_{11}1X \\ \dots \\ C_{11}NX \\ C_{12}1X \\ \dots \\ C_{12}NX \end{bmatrix}$$

where the coefficients C12αβ and C21αβ are the cross-variance values of the functions Z1 and Z2 at the points corresponding to indices α and β, and where the coefficients C11αβ and C22αβ are the covariance values respectively of the function Z1 and of the function Z2 at said points. The index X corresponds to the point referred to above as <u>x</u>.

It should be observed that the matrix which appears in this equation has the advantage of being invertible under certain calculation conditions.

In this way, using experimental covariances, the two variables corresponding to the two initial data series are resolved automatically into a common component and into two residual orthogonal components. The regularity of the data means that the experimental covariance is known for all of the distances used, so no interpolation is needed, so the matrix is defined positive.

The function then obtained is an estimate of the component that is common to both data series.

Figure 4 shows an estimate of the common component obtained from the data corresponding to the maps of Figures 3a and 3b.

It will be understood that it is particularly advantageous in numerous applications, and in particular in 4D seismic surveying, to have this common component available.

It serves in particular to eliminate non-repeatable acquisition artifacts:

· on the basis of seismic attribute grids, and in particular, for example, on the basis of root mean square (rms) amplitudes in an interval;

· on the basis of seismic time grids, and for example on the basis of seismic event times; and

· on the basis of seismic velocity volumes, and for example on the basis of automatically-determined points of origin for velocity vectors.

It may also be used in simple seismic surveying to eliminate non-repeatable acquisition artifacts:

· in particular on the basis of seismic attribute grids calculated on consecutive incidence classes, or indeed

· on the basis of seismic attribute grids calculated on volumes obtained by partial summing or converted waves.

Furthermore, once an estimate has been determined for the common component, it is possible to determine the residual components corresponding to the difference between the initial data and said estimated common component.

These residual components can themselves be resolved by kriging analysis.

This is shown in Figures 5a, 5b and 6a, 6b which are maps of white noise and of linear line noise estimated in this way for each of the two series of measurements shown in Figures 3a and 3b.

Examples of error measurements as obtained by standard filtering, by kriging analysis filtering, and by co-kriging analysis filtering (or multivariable kriging), are illustrated by the graphs of Figures 7a to 7c.

On reading these figures, it will be understood that filtering by co-kriging analysis makes it possible to obtain dispersions that are much smaller than those obtained with conventional filtering or filtering by kriging analysis, and gives better results.

The above description relates to an implementation using two series of data.

As will be readily understood, the proposed method can also be implemented in the same manner with a larger number of data series (campaigns).

Semi-automatic filtering

This second implementation also enables simplified resolving when only one seismic data series is available (function S1).

It assumes that a model of a component θm of the experimental variogram θ is previously available.

This model which is known beforehand is, for example, the model of an independent component of the subsoil geology: white noise, stripes, etc.

Knowing this model of the component θm, there is deduced therefrom the residual variogram corresponding to the difference between the experimental variogram and this component θm.

Kriging analysis is then performed in order to determine firstly the model component Sm and secondly, on the basis of the residual variogram, the orthogonal residue R1 such that:

$$S1 = Sm + R1$$

This automatic resolution enables acquisition anomalies to be filtered out when they present three-dimensional coherence that is easily identified and modeled, such as the stripes parallel to the cables that are observed in the amplitudes and times when performing offshore seismic surveys.

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